ROOT STUDIES OF GRASSES AND ALFALFA
AT MANDAN, NORTH DAKOTA

by

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B. S., Kansas State College
of Agriculture and Applied Science, 1936

A THESIS

submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1946

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INTRODUCTION

During the five years 1934-1938, the Great Plains experienced a period of soil movement by wind which is unequalled in the recorded history of man. This was a period of far below average rainfall and consequently there was not sufficient plant cover produced to afford protection to the soil from the ravages of wind. True, various tillage methods gave temporary relief, but by working dry soil frequently, it soon became pulverized and further tillage only aggravated the situation until rain fell and cemented the soil particles together again. Many believed that the area was becoming the Great American Desert, threw up their hands in despair and moved to more favored localities.

One of the cries that arose from this catastrophy was that the soil had been depleted of a large portion of its organic matter, and that if this were restored, part of the problem would be solved. The value of organic matter in controlling erosion either by wind or water is dependent upon its form. If it is in the colloidal state it binds the soil particles together forming more stable aggregates which may be more resistant to the action of wind and water. It increases the permeability of the soil thus decreasing runoff and providing more water for plant growth which in turn provides a better soil cover. In the more

or less undecomposed stage, such as straw, corn and sorghum stalks, roots, etc., it acts as a mechanical obstruction to wind and slows down the movement of water. It also breaks the impact of raindrops which would otherwise deflocculate the soil surface and permit greater runoff. Particularly in the form of roots, it ties the soil particles together thus preventing their movement by wind or water. It should be noted, however, that some soils high in partially decomposed organic matter may be more subject to wind erosion than those with less organic matter. These soils when dry are loose and ashy, and cultivation has very little effect in controlling erosion.

A serious wind erosion problem occurred in the Canadian plains during the early part of this century. Harrison (6), in 1920, stated that farmers in the wind erosion areas of Canada were emphatic in declaring that soil drifting did not start until the virgin fiber had disappeared. He stated that after the sod was broken, drifting did not commence for a period of 5 to 15 years and that the tendency to drift did not appear to be related to the lack of total organic matter in the soil but to the lack of root fiber. He recommended the use of grass rotations to maintain the soil fiber. Fairchild (5) also stated that soil drifting in Canada was due to the exhaustion of the root fiber and that this loss was greater where the land was left too often as bare fallow. Kramer and Weaver (9), working in Nebraska, have shown that roots were effective in controlling water erosion as compared with bare soil.

Since grass roots are thought to play an important role in the control of erosion, in their undecomposed state, it seemed desirable to study the rate of development of grass roots in the soil a ter seeding; the effect of soil type on root production; the quantity of roots produced by different species of grass; and how long roots remain in the soil after plowing under the sod. No measurements were made of soil erosion either by wind or water in this study, therefore no attempt is made to draw any conclusions as to the effect of roots on the control of erosion from the data obtained. These results are presented only for the information they offer in connection with soil erosion problems.

DESCRIPTION OF PLOTS AND FIELDS STUDIED

During the severe drought and wind erosion period of 1934-1938, when the people of the Great Plains were becoming more grass conscious, steps were taken to establish grass rotations at several of the dry-land stations. These were set-up to study the effect of grass on the structure, fertility and productivity of soils. Such a group of rotations were established at the Northern Great Plains Field Station at Mandan, North Dakota in 1937.

The area selected for these studies is that known as the south field. From 1914 to 1935 inclusive this area was devoted mainly to rotations of annual crops and tillage practices which were duplicates of those in the main field. Due to the heavy

nature of the soil, a silty clay loam, and to the slope of the land, it was subject to considerable runoff and erosion. It was therefore thought best to discard the annual crop rotations and put grass rotations in their place. Since the area suitable for the rotations was limited, replication was impossible. The field was uniformly cropped to oats in 1936 and 1937 and grass seeding attempted in the fall of 1937, except the area upon which rotation 1G is located. Agropyron pauciflorum (Shwein.) Hitch. was the only grass which produced a stand from this seeding. It was not until 1939 that stands of the other grasses were secured with the exception of Elymus canadensis L. which did not produce a stand until 1940.

A diagram of the south field showing the location of the various rotations and plots sampled is presented in Fig. 1. Rotation 1G is on an area which had been in Agropyron cristatum (L.) Gaertn. since 1923. In this rotation one plot of grass is plowed each year. Flax follows the sod after which corn and wheat alternate. Rotation 2G consists of 12 plots and is on an area which was in continuous wheat and small grain on fallow from 1914 to 1935. One grass plot is broken each year followed by flax, corn, and wheat. One plot is also seeded to grass each year in the wheat stubble. Rotations 3GD and 4GD are located on the area which was formerly occupied by continuous corn and alternate corn and fallow. They each consist of three plots and are called deferred grass rotations, that is, one plot is seeded to grass which remains for approximately six years. The other

SOUTH FIELD (C)
Northern Great Plains Field Station
Mandan, North Dakota

Fig. 1. South field plan showing plots sampled (X) in 1944 for root studies.

two plots are in corn and wheat which alternate until one is seeded to grass. Breaking of the old sod is delayed until a new stand of grass is established. Flax follows the sod after which it is dropped from the rotation and corn and wheat continue to alternate. A. cristatum was used in rotation 3GD and A. pauciflorum in rotation 4GD. However, since the latter is short lived, it was not included in the seedings made in 1945 and Stipa viridula Trin. was substituted for it. Rotations 5GD, 6GD, 7GD, and 8GD are somewhat similar to 3GD and 4GD except they have three annual crops which rotate instead of two, namely, corn, wheat, and oats. The species of grass used in these rotations are Agropyron smithii Rydb., E. canadensis, Elymus junceus Fisch., and A. cristatum, respectively. Rotations 5GD and the A and B plots of 6GD were formerly in continuous oats or alternate oats and fallow. The C and D plots of rotation 6GD and all of the plots in 7GD were in miscellaneous crops from 1914 to 1922 and in a rotation of A. cristatum, flax, and corn from 1923 to 1935. The area upon which 8GD is located was formerly in rotations of two years small grain and one year of fallow. Rotation 10G is similar to 1G except A. cristatum was seeded in 1939 instead of 1923. The area upon which it is located was formerly in continuous and alternated crop and fallow of wheat, oats and barley. Rotation 41GD is located on land formerly in continuous and alternate barley and fallow. It consists of three plots of Bromus inermis Leyss. and one each of corn, wheat, and oats. The annual crops rotate for four years at which time

one of the plots is seeded to B. inermis. If a stand is obtained, the oldest stand of brome sod is broken and seeded to flax. Flax then drops out of the rotation and the other three annual crops continue to rotate. Rotation 42GD is located on land formerly in continuous and alternate corn and fallow. It is similar to rotation 41GD except it contains alfalfa instead of B. inermis. Rotation 49M is a two year rotation of wheat and corn and acts as a check on the other rotations which contain grass. The area upon which it is located was formerly in a rotation of two years small grain and one of fallow.

Rotations 41GD, 42GD, and 49 are also being conducted in the main field, which is a fine sandy loam soil. Rotation 49 differs from 49M in that the former is fall plowed and the latter spring plowed. The root content of the soil in these rotations was compared with those in the south field to determine the effect of soil texture on the production of roots.

EQUIPMENT AND METHOD OF STUDY

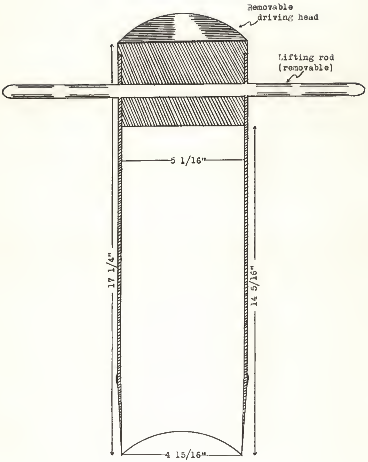
The equipment used in the collection of the samples was as follows: A metal tybe (Plate I), a Farmall H tractor, hydraulic jack, wooden blocks, corn knife, small flat bed wagon, measuring stick, spade, and cloth bags. Five locations were sampled per plot at 0 to 6 and 6 to 12-inch depths. The five locations were in line in the center of the plot running lengthwise. At each location the tube was placed over a grass plant in a vertical

position and the tractor was then moved over it so that the rear axle was directly above the tube head (Plates II and III). In the case of the corn plots, the tube was placed at approximately one-fourth the distance between rows. The hydraulic jack was then placed on the head of the tube with the head of the jack against the axle of the tractor. Thus by operating the jack, the tube was driven into the soil. Because of the short lift of the jack, blocks were necessary in order to drive the tube to the required depth. The tube was driven into the soil approximately 14 inches, and the tractor was then moved out of the way. The driving head of the tube was removed and the iron rod replaced. In order to remove the tube from the south field soil, a silty clay loam, it was first necessary to loosen the soil from around the outside of the tube by means of a spade. This operation was unnecessary in the main field. The column of soil was broken at the cutting point before lifting by turning the tube. However, it was found that the column of soil did not always turn with the tube, and to overcome this, a corn knife was forced down through the soil column in such a way that it was adjacent to the lifting rod. Thus when the tube was turned the lifting rod would be forced against the corn knife which would cause the soil column to rotate with the tube. After the soil column was broken, the tube and soil column were then removed together by hand and placed on the small flat-bed wagon which was connected to the tractor. The wagon was found to be a convenient place to work and was also a means for hauling the necessary equipment and soil

EXPLANATION OF PLATE I

Metal tube used for root sampling.

PLATE I


Removable driving head
Lifting rod (removable)
5 1/16"
17 1/4"
14 5/16"
4 15/16"

EXPLANATION OF PLATE II

Placing the tube over the grass plant preparatory to sampling.

PLATE II

EXPLANATION OF PLATE III

Placement of the tractor and hydraulic jack over the the tube preparatory to jacking the tube into the soil.

PLATE III

samples. By shoving against the soil column with the hand, at the cutting end of the tube the soil column was moved toward the head end so that only the above ground parts and the crowns of the grass were exposed. Then by placing the corn knife flush with the head of the tube, the leaves and crowns of the grass were cut away and only the roots remained in the soil column (Plate IV). The soil column was then moved through the tube so that only six inches were exposed and this was cut in the same manner as described above. The same procedure was also followed for the six to twelve inch depth and the samples were then placed in separate cloth bags. After the samples were collected, they were air-dried and stored until late fall when more time was available for extracting the roots from the soil. Four-hundred samples were collected from 40 plots and areas.

The problem of removing the roots from the soil was studied rather thoroughly and several techniques were tried. It was thought that Pavlychenko's (14), and Shively's and Weaver's (17) spray method would be too time consuming as well as Stevenson's and White's (21) divided tank method. The apparatus finally used was as follows (Plate V): An Eberbach, general purpose, two-speed, box type shaker was purchased. The box of this was removed and a metal tank 16½ inches long, 10 3/4 inches wide, and 11½ inches high was set in its place. The tank was held in place by means of a low wooden rack which was fastened to the frame work of the shaker. Thus the tank could readily be removed, but would be held firmly in place when the machine was

EXPLANATION OF PLATE IV

Cutting the crowns of the grass plant from the soil core.

PLATE IV

EXPLANATION OF PLATE V

Equipment used for washing roots from the soil.

PLATE V

in operation. A basket, slightly smaller than the tank, was constructed from a separator screen with holes 1/16 inch in diameter. When placed in the tank, it rested on a support which held the basket approximately 1 3/4 inches from the bottom of the tank. The machine was run on low speed at 200 excursions per minute. The procedure for root extraction was as follows: The samples were placed in separate battery jars and soaked in water for several hours. One sample at a time was then transferred to the screen basket in the tank. Water was run into the tank until the soil was covered. The shaking machine was then started and run until all the soil had been washed through the screen, which required only about one or two minutes. The roots in the basket were then transferred to another screen and the water in the tank was decanted through the screen in order to save any roots which might have escaped through the basket. Only a small amount of roots were found in the water. The roots were then washed by means of a spray of water and all soil particles which adhered to the roots were removed. Some samples contained considerable partly decomposed organic matter, and it was found that with careful manipulation of the screen and spray, most of this could be removed, the remainder was picked out by hand. Where there were a considerable number of rocks, these were removed by placing the sample in a pan of water and allowing the rocks to settle out. The roots could then be readily poured on to the screen. The roots were placed in the ordinary soil cans and dried at 95

degrees centigrade. After drying they were weighed to the nearest one-hundredth of a gram.

REVIEW OF THE LITERATURE

Many investigators were interested mainly in studying and charting the entire root systems in order to determine the different types of root distribution of various plants. Other investigators were interested in studying the quantity of roots produced under various conditions and by various species, particularly in the more shallow depths. Since this study deals mainly with the quantity of roots, most of the literature cited will refer to that phase of study. The literature is grouped according to the subject with which it deals.

Methods of Study

Various methods of studying and charting the entire root system of plants have been used. Pavlychenko (14) described his soil-block washing method and reviewed the methods of some of the other investigators which were as follows: Hale's direct washing method, Schubart's trench-washing method, Nobbe's water culture and soil container method, Hellreigel's steel cylinder method, Hay's steelframe method, King's soil prism washing method, Schulze's concrete compartment washing method, Rotmistroff's observation pit method, Headden's di-

root tracing of main roots method, and Weaver's trench tracing method. Tharp and Muller (23) studied the entire root system by the bisect wash method. Koval (8) used a current of air to uncover the roots. Weaver and Zink (28) studied the growth of roots in boxes with removable sides.

Some investigators were interested mainly in the quantity of roots produced and not so much in charting the entire root system. In these studies Shively and Weaver (17) took samples to a depth of four inches and washed out the roots on a screen with a fine spray. Blaser (2) developed a rapid method of sampling and washed the soil from the roots with a fine spray. Stevenson and White (21) used a divided tank method.

Increase of Roots With Age of Stand

Weaver and Zink (28) working in Nebraska reported the seminal roots of 14 species of native and introduced perennial grass to be from six to ten inches deep at the age of 21 days. From 90 to 123 days of age, they had extended to 24 inches. Burton (3) of Georgia seeded _Paspalum notatum_ Flugge., _Paspalum malacophyllum_ Trin., _Paspalum urvillei_ Steud., _Paspalum dilatatum_ Poir., _Digitaria eriantha_ Steud., and _Axonopus affinis_ Chase. in April and examined the roots in December. He found they extended in depth from 36 to 44 inches. Stevenson and White (21) observed in Canada that the Fairway variety of _A. cristatum_ increased in root content at a fairly

uniform rate up to seven or eight years of age. Production ranged from 2665 pounds per acre foot for the one year old stand to 8055 pounds for the eight year old stand. The standard variety of A. cristatum reacted approximately the same as the Fairway variety except it was slightly lower in root production in the older stands. B. inermis developed in much the same way as A. cristatum except its yield of roots was slightly lower. A. pauciflorum was much lower in root fiber content and its rate of increase was very slow. Five-year old stands contained very little more than one-year old stands of A. cristatum or B. inermis.

Soil Conditions and Root Growth

The rate of increase and the amount of roots produced are dependent to a certain extent on such soil conditions as fertility, moisture, pH, texture, and aeration. Sprague (19), working in New Jersey with Agrostis palustris Huds. (Virginia creeping bent strain), found some evidence that the provision of nitrogen in a readily available form tends to restrict root growth as compared with the application of nitrogen in a slowly available form. High ratios of soluble nitrogen to carbohydrate reserves were shown to favor top growth rather than root development. He concluded that early spring applications of available nitrogenous fertilizers in abundance may reduce the quantity of new roots formed and thus limit the utilization of

the soil resources for the remainder of the season. Root abundance was not correlated with either the supply of available phosphorus or the organic carbon content. He found that where grass was grown in soils with a pH of 5.5 or less, the root production was greater than in soils with a higher pH value. Ammonium sulphate fertilizer developed a pH of 5.0 and sodium nitrate a pH of 6.3. The yield of grass roots on the former was nearly six times that of the latter. He stated that the acid condition may have been unfavorable for decomposition of the roots, for many of them appeared brown and non-functional, thus with decomposition reduced, the root content would increase.

Willard and McClure (29) reported that under their conditions in Ohio, the application of 10-6-4 fertilizer tended to restrict the root development of Poa pratensis L. the first year in comparison with an unfertilized area. Laird (10) working with Capriola dactylon (L.) Kuntze., Capriola dactylon Var. St. Lucie (L.) Kuntze., and Eremochloa ophiuroides (Munro) Hack. in Florida obtained an increase in root development by applying a three inch layer of clay to Norfolk sand, except in case of the latter grass. Ammonium phosphate alone produced a greater quantity of roots than the clay alone, but both of them together produced the best root development for all grasses except the St. Lucie variety of C. dactylon. Weaver, Jean, and Crist (27), studying the effect of sodium nitrate on the roots of various crops and grasses in Nebraska, found that this fertilizer caused the roots to develop more abundantly and more profusely.

They also retarded normal penetration into the soil below. Weaver (24), working with the native grasses of South Dakota, Nebraska, Kansas, and Colorado, observed that there was a marked increase in root branching when roots growing in a compact layer of soil entered a less compact area, and suggested that this was probably due to an increase in aeration. Rogers (16), studying the root development of apple trees in England, reported that the root spread was two to three times the branch spread in sandy soils and 1.6 times that in loam and clay soils. The sand produced the smallest trees, clay produced medium size trees, and loam the largest. Shively and Weaver (17) studied the effect of precipitation on root development of native grasses in Iowa, Nebraska, Kansas, and Colorado, and found that as the precipitation decreased, root development also decreased.

Plant Treatment and Root Growth

Several investigators studied the effect of frequency and height of mowing, root pruning, and time of seeding on root development, and found that these factors were quite influential in root growth. Sprague (19), working in New Jersey, reported that close mowing (1/4 inch) reduced the quantity of roots produced by *Agrostis tenuis* Sibth., *Agrostis palustris* Huds. (seaside strain), and *Agrostis canina* L. Root development of *P. pratensis* was not influenced by mowing at the height of 7/8 inch, whereas mowing at this height reduced the root development of

Agrostis alba L. Laird (10), working in Florida, observed that mowing Cynodon dactylon (L.) Pers. and Eremochloa ophiuroides (Munro) Hack. often enough to prevent seed formation not only increased the root development, but also produced a better sod than non-mowing. This, however, was not true for Stenotaphrum secundatum (Walt.) Kuntze. Bukey and Weaver (1) showed that under Nebraska conditions severe clipping of Andropogon furcatus Muhl. and Andropogon scorparius Michx. decreased the amount of food stored in the roots and resulted in their destruction in a few years. Priestly and Evershed (15), working in England, showed that removal of succulent leafage of Tradescantia zebrina Schnizl., and Solanum lycopersicum L. tended clearly to unbalance or actually destroy any rhythm that might exist between top and root growth. They concluded that defoliation is definitely correlated with the extent of root growth. Parker and Sampson (13) reported that in California frequent removal of aerial growth of Stipa pulchra Hitchc. and Bromus hordeaceus L. resulted in poorly developed root structure and found that the roots were also devoid of hairs. They concluded that where a robust root system is required to bind the soil to control erosion, frequent leafage removal should be avoided.

Nedrow (12), working in Nebraska, observed that clipping the tops of Sudan grass at a height of four inches caused an 85 percent reduction in growth of both roots and tops. He also found that pruning the roots at a depth of five inches caused a

50 percent decrease in the root quantity. Keim and Beadle (7) studied the effect of time of seeding of the grasses -- B. inermis, Phleum pratense L., and P. pratensis, and the legumes-- alfalfa, red clover, and white biennial sweet clover in Nebraska on their root development and winter survival. They concluded that early seedings as in August produced the best root development, and that the plants were more able to survive the winters.

Root Production of Grass Species

Literature on the root production of the species discussed in this study is rather limited. Stevenson and White (21) reported that in Canada, A. cristatum and B. inermis had approximately the same root content, while A. pauciflorum was considerably less in root content. At the age of five years, their yield of roots per acre foot was 6229, 5768, and 2901 pounds, respectively. Harrison (6) reported that no blowing occurred in Canada where B. inermis was being grown, but that blowing did occur where Phleum pratense L. and western rye were being grown. Kramer and Weaver (9) studied the effect of various grass sods in Nebraska with the tops removed on water erosion control and found B. inermis roots to be very effective in controlling erosion. Weaver and Harmon (25), also studying the effect of the roots of various species of grass on water erosion control in Nebraska, reported that the quantity of roots was not always

indicative of erodibility. P. pratensis contained nearly 39 percent less roots in the surface four inches of soil than A. furcatus, but their erosion rates were nearly the same.

Sprague (19) showed that fully half of the root systems of P. pratensis and Agrostis tenius Sibth. in New Jersey were generated each spring. P. pratensis produced its maximum weight of roots early in May and A. tenius the latter part of May. Stukey (22), working in Rhode Island, classified grass species into two groups according to their habit of root growth. One group produced new roots annually, root production being very active from about the middle of October into December, but during the cold months it practically ceased. Growth was resumed in March and reached its maximum in April. From April on it became slow and practically stopped in late June, and the old roots disintegrated soon after the new roots became established. This group included Phleum pratense L., Festuca elator L., Agrostis tenius Sibth., Lolium perenne L., and Agrostis alba L. In the other group, roots persisted during the two years studied. However, their growth habits the first year were similar to those in the first group, but after that period there was little production of new roots. Likewise, there was limited root disintegration. Grasses included in this group were: P. pratensis, Poa compressa L., A. cristatum, Phalaris arundinacea L., and Dactylis glomerata L.

Rate of Decomposition of Plant Material

Several investigators found that the rate of decomposition was dependent to a certain extent on the nitrogen-carbon ratio. Spaulding and Eisenmenger (18) reported that from their work with various plant materials in Massachusetts there was no strict correlation between the rate of decomposition and the carbon-nitrogen ratio, but plants containing the most nitrogen decomposed the more readily. They found that if the plant material had a ratio of carbon to nitrogen of no more than 25 or 30 to 1, the material decomposed readily and that the lignin and pentosan content affected its rate of decomposition. Millar, Smith, and Brown (11), working in Iowa with various plant materials, observed that those relatively high in nitrogen decomposed more rapidly the first few days. However, after this initial period, those low in nitrogen decomposed more rapidly. Doughty (4) studied the rate of decomposition of the roots of several forage plants in Canada and found that the rate was closely correlated with the carbon-nitrogen ratio. The order of decomposition with the most rapid first was alfalfa, _A. pauciflorum_, _B. inermis_, _A. cristatum_, and _Carex filifolia_ Nutt. Their carbon-nitrogen ratios were 21.3, 24.0, 31.2, 30.0, and 45.2, respectively. Preliminary work with _Stipa comata_ showed its rate of decomposition to lie between _C. filifolia_ and _A. cristatum_. Roots of _A. smithii_ decomposed at about the same

rate as did those of A. cristatum. Stevens (20), in discussing C. filifolia (niggerwool), stated "The outstanding characteristic of niggerwool is its great abundance of tough wiry black roots, which persist for several years even after the plant is dead. Old trails in western North Dakota are often bumpy because of the persistent hummocks formed by the roots of niggerwool".

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results are presented by dividing the data into groups according to the comparisons to be made. Each group is discussed separately. The root content of the individual samples together with the plot sums and averages are presented in the Appendix.

The Variability of the Quantity of Roots of A. cristatum in Different Plots with Five Year Old Stands

Only A. cristatum data permitted a study of plot variability. All other species were represented by only one plot. There were six A. cristatum plots available for these studies. The quantity of roots in pounds per acre for the 0 to 6 and 6 to 12-inch depths is presented in Table 1. The 0 to 6-inch layer of soil contained on the average 76.5 percent of the total root content in the upper foot. This is in agreement with the

results obtained by Stevenson and White (21) working with A. cristatum in Canada. Weaver, Hougen, and Weldon (26), studying the roots of A. furcatus and A. scoparius in Nebraska, found nearly 60 percent of the entire root system to be in the upper six inches of soil.

Table 1. The quantity of A. cristatum roots in pounds per acre in the 0 to 6 and 6 to 12-inch depths of six plots with 5-year old stands in the south field.

Depth inches	2G-C	2G-D	2G-L	3GD-A	8GD-A	10G-G	Average	F value*	L.S. Dif. 5% lbs
				pounds					
0- 6	2220	2790	1550	3240	1760	1640	2200	10.34**	620
0-12	470	1190	460	850	510	590	680	10.13**	270
Total	2690	3980	2010	4090	2270	2230	2880		

* F value required for significance at 5 percent level, 2.62; at 1 percent level, 3.90.
** Highly significant.

It is evident that there is a very highly significant difference between the root contents of the various A. cristatum plots. The comparatively high root yield of plot 3GD-A is probably due to its favored location, for it has been noted that runoff water drains over this plot. This would stimulate top growth and root development. Since it is evident that this plot is in a favored location, it will be omitted from the discussion which follows. Plot 2G-L, 8GD-A and 10G-G are somewhat similar in their root contents although they are rather scattered as to

location, as is shown in Fig. 1.

It will be noted that plot 2G-D is considerably higher in root content than 2G-C. These plots are side by side in the field and thus the soil should be similar. The top growth of these plots did not reflect marked differences in the soil or root development. There is one possible explanation for these differences and that is, the time of sampling. Plot 2G-D was sampled in the spring because it was to be plowed and seeded to flax, whereas 2G-C was not sampled until early fall. The work of Sprague (19) and Stukey (22) showed that the quantity of roots in the soil is constantly changing and that many species reach their maximum in root production for the season in the spring, after which many of the old roots die and disintegrate. It is entirely possible that the root content of A. cristatum is higher in the spring when root growth is more active, than in the early fall when the grass is more or less dormant, and this might account for the difference between plots 2G-C and 2G-D. Further evidence that A. cristatum may have a greater root content in the spring than in the fall is brought out by comparing the root contents of plots 1G-F and 1G-G which were seeded in 1923. Plot 1G-G was sampled in the spring and contained 4510 pounds of roots in the upper acre foot of soil. Plot 1G-F was sampled in the early fall and contained 3050 pounds. Certainly soil differences are not entirely responsible for this wide variation in root content. However, plot 10G-G was also sampled in the spring and its root content was compar-

atively low. The root content from this plot was either not affected by time of sampling, or else the soil in this location is much poorer than in the remainder of the field.

It is evident, however, from this discussion that the grass root content of the soil is quite variable. This is in line with the results obtained by Willard and McClure (29) working with P. pratensis in Ohio. They found a range of from 5960 to 12960 pounds per acre with a standard deviation of ± 1963 pounds on what appeared to be a uniform stand. Not only are the quantities of roots influenced by differences in soils, moisture, frequency of mowing, etc., but also may vary considerably during the growing season on a given plot, and if the maximum quantity of roots of a species is desired, sampling should be done at the end of the period of most active growth.

The Increase in Root Content of A. cristatum With Age of Stand

Grass to be of most value in soil improvement, should have the ability to build up the root fiber content of the soil in as short a time as possible. Its beneficial effects could then be distributed over the land more frequently. The south field contained several plots of A. cristatum ranging in age from one to five years, with two additional plots 21 years of age. Root samples were taken on these plots in the early fall

of 1944 to depths of 0 to 6 and 6 to 12 inches. The results are charted in Fig. 2, showing the relationship between the age of stand and the production in pounds of roots per acre foot.

It is evident from these results that the greatest increase in the production of roots occurred within the first three or four years. Total production continues to increase after that time but at a slower rate. Thus it would appear that the most economical time to break A. cristatum sod, from a root production standpoint, would be when it is at the age of three to four years. These results are not in agreement with those of Stevenson and White (21) who found that A. cristatum continued to increase in root production for eight years - the length of their study. Many factors such as soil reaction, fertility, moisture and frequency of mowing influence the production of grass roots as shown in the literature review. Therefore, the results obtained at one location would not necessarily be applicable to another area.

The Effect of Soil Type on the Root Production of Grass, Alfalfa, Wheat, and Corn

The soil of the south field is a silty clay loam and that of the main field is a fine sandy loam. Rotations 41GD, 42GD, and 49 are located in both fields and are excellent for studies to determine the effect of the two soil types on the production of roots of various crops and grasses. A virgin

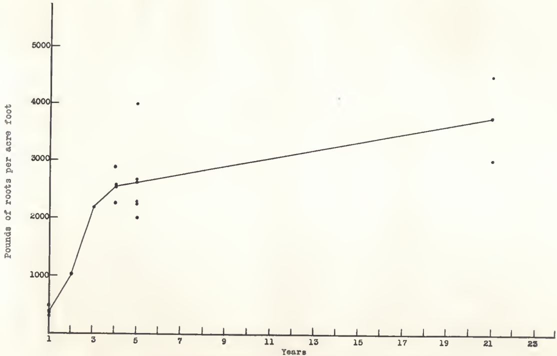


Fig. 2. Increase in roots of _A. cristatum_ with age of stand.

area was also sampled at the south end of the south field and one east of the east residence. The latter is on the same type of soil as the main field. A comparison of the quantity of grass, alfalfa, wheat, and corn roots in pounds per acre in the two soils is presented in Table 2.

In every case root production in the south field was higher than in the main field, except for the two plots of alfalfa in the 6 to 12-inch depth. The reason for the higher root content of alfalfa at this depth in the main field is not definitely known, but it is possible that it may be due to its deep rooting habits. Since a sandy soil would be more conducive to deep root penetration than a heavier soil, both because of its more open structure, and deeper moisture penetration, alfalfa could conceivably be expected to have a higher root content in lower levels of light soils than on heavier types.

Thus from these data it is quite evident that root production is considerably higher on the heavy soil of the south field, than on the lighter soil of the main field, with the possible exception of alfalfa in the 6 to 12-inch depth. This is in agreement with the work done by Laird (10) in Florida.

Root Content of Various Species of Grass With Four and Five Year Old Stands

Only single plots were available for the study of the root development of various grass species, except in the case of A. cristatum. An average of all the A. cristatum plots ex-

Table 2. A comparison of the quantity of grass, alfalfa, wheat, and corn roots in pounds per acre in the fine sandy loam soil of the main field and the silty clay loam soil of the south field in 1944.

Soil	B. inermis Rotation		Alfalfa Rotation		Wheat Rotation	Corn Rotation	Virgin sod (4)
	4[illegible]D-8 (1)	4GD-[illegible] ([illegible])	4[illegible]D-8 ([illegible])	4[illegible]D-[illegible] ([illegible])	[illegible]	[illegible]	
	pounds						
			0 to 6 inches				
S. clay loam	3230	260	9790	1830	140	40	3240
F. sandy loam	2300	120	8460	960	40	30	2720
Difference	930	140	1330	870	100	10	520
			6 to 12 inches				
S. clay loam	1100	120	2640	350	70	50	1110
F. sandy loam	520	40	2740	610	20	20	890
Difference	580	80	-100	-260	50	30	220
			Total 0 to 12 inches				
S. clay loam	4330	380	12430	2180	210	90	4350
F. sandy loam	2820	160	11200	1570	60	50	3610
Difference	1510	220	1230	610	150	40	740

(1) Seeded in 1938 on the fine sandy loam soil and in 1939 on the silty clay loam soil.
(2) Seeded in 1944.
(3) Seeded on both soils in 1938 and reseeded in 1940 on the fine sandy loam soil to thicken the stand.
(4) Virgin sod sample on fine sandy loam soil was taken east of the east residence which is on the same soil type as the main field, that on the silty clay loam soil was taken at the south end of the south field.

cept 5GD-A is used to compare with the other species. The results of this study are presented in Table 3 together with the root content of virgin sod located at the south end of the south field. The data for A. pauciflorum are not presented, since this species had died and no plants remained at sampling time.

Table 3. Root content in pounds per acre of five species of grass from four and five year old stands, and one native sod area in 0 to 6 and 6 to 12-inch depths in the south field.

Depth in-ches	E. canadensis (1) 6GD-A	A. cristatum (2) average	A. smithii 5GD-A	E. junceus 7GD-A	B. inermis 41GD-B	F value*	L.S. Dif. @ 5%	Native sod(3)
	pounds						pounds	
0 to 6	1030	1990	2120	2610	3230	13.91**	640	3240
6 to 12	250	640	620	870	1100	16.60**	230	1110
Total	1280	2630	2740	3480	4330			4350

* F value required for significance at 5% level, 287; at 1% level 4.43.

** Highly significant.

(1) Four year old stand of E. canadensis, all others were five five year old stands.

(2) Average of plots 2G-C, 2G-D, 2G-L, 8GD-A, and 10G-G.

(3) Native sod not included in statistical analyses.

It will be noted that B. inermis was significantly higher than any of the other cultivated grasses in root production with the exception of E. junceus, and it was on the border line. In five years, the root production of B. inermis was nearly equal to native sod. All rhizomes were included in the weights of roots, therefore B. inermis and A. smithii are favored some-

what over the other grasses. It is questionable whether E. junceus is significantly higher than either A. cristatum or A. smithii, but it is definitely better than E. canadensis. A. cristatum and A. smithii were equal in root content and were definitely superior to E. canadensis. Although E. canadensis had a stand one year younger than the other grasses, this difference in age would certainly not account entirely for its lower root yield. The poor root development of E. canadensis was rather surprising, for it has been the highest in hay production of all the grasses studied in the south field. It may be, however, that a small root system is advantageous to high hay production, for the grass may not become root bound so soon as one with greater root production such as B. inermis. A small root system would, however, probably be detrimental during periods of low rainfall. The results of this study with B. inermis and A. cristatum are contrary to the results of Stevenson and White (21) who found that B. inermis and A. cristatum produced approximately the same quantity of roots. However, in their study they discarded the rhizomes of bromegrass and therefore their data deal only with the fibrous roots. Their yields of roots were considerably higher than those found in this study. They found that a five year old stand of A. cristatum contained 6229 pounds of roots per acre foot and the same age stand of B. inermis contained 5768 pounds.

The size of the roots of the various species in this study was determined by observation only. The roots increased in

coarseness in the following order: B. inermis, A. cristatum, and native sod (mostly Bouteloua gracilis (H.B.K.) Lag.), A. smithii, E. junceus, and E. canadensis. Stevenson and White (21) reported that the roots of A. cristatum were larger and stronger than those of B. inermis.

Root Content of Various Species of Grass Seeded in 1943 and 1944

New seedings of various species of grasses were made in the fall of 1943. Stands were obtained with some species, but it was necessary to reseed others the following spring in order to thicken the stand. S. viridula did not emerge until the spring of 1944. Root samples were taken in the early fall of 1944 and an attempt was made to sample only those which had emerged in the fall of 1943. The age could not always be determined accurately.

These samples were taken to determine the amount of growth made by various species during the first year. Also it was thought these data might be of value to compare with those collected in the future from the same plots. There were three A. cristatum plots sampled and analysis of variance showed that there was no significant difference in their root production in either the 0 to 6 or 6 to 12-inch depths. Therefore, the average of these was used to compare with other species. The root content of the various species of grasses is presented in Table 4.

Table 4. Root content in pounds per acre of six species of grass (1943-1944 seedings) in the 0 to 6 and 6 to 12-inch depths in the south field, 1944.

Depth in-ches	*S. viridula* 4GD-C	*A. smithii* 5GD-D	*B. inermis* 41GD-E	*A. cristatum* (1) average	*E. junceus* 7GD-D	*E. canadensis* 6GD-D	F value*	L.S. Dif. 5% level
	pounds							
0- 6	220	290	260	300	340	480	4.59**	123
6-12	90	90	120	100	120	190	2.40	none
Total	310	380	380	400	460	670		

* F value required for significance at 5% level, 2.62; at 1% level, 3.90.
** Highly significant.
(1) Average of plots 2G-G, 3GD-C, and 8GD-D.

Since there was a rather heavy growth of *Setaria viridis* (L.) Beauv. (pigeon grass) and other weeds over these plots, part of these yields may include the roots of weeds. However, the growth of we ds was fairly uniform for all of the plots, so the yields should be comparable.

It will be noted that for the 0 to 6-inch depth, *E. canadensis* was significantly higher than any of the others. There was no significant difference between the remaining species. For the 6 to 12-inch depth, there was no significant difference between any of the species.

These yields of roots are quite low particularly when compared with those obtained by Stevenson and White (21) working in Canada. They found that *A. cristatum* produced 2665

pounds of roots per acre foot the first year while B. inermis produced 2898 pounds. Willard and McClure (29), working in Ohio with a one year old stand of P. pratensis, obtained 4380 pounds of roots per acre from the upper six inches where no fertilizer had been applied and 3880 pounds where a 10-6-4 fertilizer had been used.

Either the climatic and soil conditions at Mandan were very unfavorable for root growth as compared to those under which the other investigators were working, or else the methods of sampling do not give the same results.

Loss of Roots After Plowing

The most accurate way to determine the loss of roots after the sod is broken is to sample the sod before plowing and at yearly intervals thereafter until the roots disappear. However, since this study was conducted during one season, it was impossible to obtain data over a longer period.

An indication of the loss of A. cristatum roots can be obtained from plots 2G-E and 2G-F in the south field on which the sod was plowed 1½ years and 2½ years respectively prior to sampling. At sampling time the former was in corn and the latter in wheat. By comparing the root content of these plots with that from wheat and corn land in a non-grass rotation, some idea of the amount of grass roots remaining can be obtained. It is realized that this assumption may not be entirely correct,

for the root content of corn and wheat in a grass and non-grass rotation may not be the same. These data are presented in Table 5.

Table 5. The quantity of *A. cristatum* roots remaining in the soil at 0 to 6 and 6 to 12-inch depths in pounds per acre, $1\frac{1}{2}$ and $2\frac{1}{2}$ years after the sod was broken in the south field.

Depth in-ches	Root content in pounds per acre					
	Corn land		*A. cristatum* roots (1) $1\frac{1}{2}$ years after plowing	Wheat land		*A. cristatum* roots (1) $2\frac{1}{2}$ yrs. after plowing
	$1\frac{1}{2}$ years after plowing sod	in non-grass rotation		$2\frac{1}{2}$ yrs. after plowing	in non-grass rotation	
			pounds			
6- 0	270	40	230	250	140	110
6-12	220	50	170	190	70	120
Total	490	90	400	440	210	230

(1) There was an intervening crop of flax between corn and *A. cristatum* in case of the $1\frac{1}{2}$ year comparison, and flax and corn were the intervening crops between wheat and *A. cristatum* in case of the $2\frac{1}{2}$ year comparison. The quantities of *A. cristatum* remaining may include roots from these intervening cultivated crops.

A better understanding of the loss of roots during these periods would have been obtained if the root content of these plots had been known prior to the time of plowing. However, an indication of their root content prior to plowing can be obtained by assuming it to be similar to other plots with the

same age stands. The stand of *A. cristatum* on the plot which was plowed $1\frac{1}{2}$ years ago was approximately three years old and the stand on the one plowed $2\frac{1}{2}$ years ago was approximately two years old. Plots with stands of the same ages as these contained 2220 and 1010 pounds of roots per acre foot respectively. Thus from these data, it appears that there has been a very high loss of roots in the short periods of $1\frac{1}{2}$ and $2\frac{1}{2}$ years.

Millar, Smith and Brown (11), Spaulding and Eisenmenger (18) and Doughty (4) have shown that the rate of decomposition of plant material is dependent to a certain extent upon the carbon-nitrogen ratio of the material. The latter investigator also showed that the roots of various species of grass vary in their carbon-nitrogen ratios. Therefore, it is entirely possible that the roots of other grass species would remain undecomposed in the soil for a longer period of time.

In connection with the loss of grass roots after plowing, it is of interest to note the resistance *C. filifolia* (niggerwool) has to decomposition. While the grass roots were being washed from the samples of the main field, it became apparent that there was also a considerable quantity of *C. filifolia* roots in the samples. Since this sedge had not grown on this field after the sod was broken in 1915, it was thought that it would be of considerable interest to determine the quantity of roots remaining in the soil. Being black in color they were readily separated from the grass roots by hand. Doughty (4)

reported that *C. filifolia* roots were quite resistant to decomposition due to its high carbon-nitrogen ratio, but to find measurable quantities of these roots in the soil after 31 years of cultivation was surprising. Stevens (20) also noted the resistance of these roots to decomposition.

The south field samples contained a slight amount of *C. filifolia* roots, but the quantity was so small and variable they were not measured, but were picked out and discarded. The quantity of *C. filifolia* roots found in the various plots in the main field and in a virgin area on the same soil type is presented in Table 6.

Table 6. The quantity of *C. filifolia* roots in pounds per acre in the 0 to 6 and 6 to 12-inch depths in the main field and in a virgin area, 31 years after the sod was broken.

	Rotation and plot							Virgin
Depth	41GD-B	41GD-E	42GD-B	42GD-E	V49-A	V49-B	Average	sod (1)
0- 6	150	230	90	220	300	330	220	240
6-12	90	220	90	300	170	200	180	260
Total	240	450	180	520	470	530	400	500

(1) Samples taken east of east residence on soil type similar to main field.

There are three things of particular interest in the table: (1) The large amount of undecomposed roots of *C. filifolia* remaining in the soil 31 years after the sod was broken,

particularly in plots 42GD-E and V49-B; (2) The smaller amount of *C. filifolia* roots found in virgin sod than was expected. This would indicate that the virgin area from which the samples were taken either was much lower in the quantity of roots of this sedge than the main field before the sod was broken, or, else very little decomposition of roots has taken place; (3) There are two plots which stand out because of their comparatively low root content of *C. filifolia*, namely 41GD-B and 42GD-B. In checking back over the history of these plots, it was found that the former had been in *B. inermis* 23 out of the 31 years, and the latter had been in alfalfa 19 out of the 31 years. Plots 41GD-E and 42GD-E which are the nearest to these plots and which would be the most comparable, contained considerably more roots of this sedge. In checking back in the history of these plots, it was found that the former had been in *B. inermis* 16 years out of the 31 and the latter had been in alfalfa 13 years out of the 31. In other words, the plots which contained the smaller quantities of sedge roots had been in grass and alfalfa from six to seven years longer. This lower root content could be due either to these plots having a lower original sedge root content, or else grass and alfalfa directly or indirectly caused a more rapid decomposition of sedge roots. If the latter is true, the reason for it would be difficult to explain, unless bacterial action was greater in those plots which had grown grass or alfalfa for longer periods, which would in turn act upon the sedge roots and cause a more rapid decompo-

sition.

SUMMARY

Root studies were made on different species of grass and alfalfa in the south and main fields to determine how rapidly grass roots are formed in the soil after seeding, the effect of soil type on root production, the root content of different species of grass, and how long they remain in the soil after plowing under the sod.

A method was devised whereby the samples were taken by means of a metal tube, hydraulic jack and a tractor, and the roots were washed from the soil by means of a motor driven shaker.

The following results were obtained:

(1) There was considerable variation between plots of A. cristatum of the same age stand. These highly variable results may be a limiting factor in grass root studies.

(2) The rate of increase in quantity of roots of A. cristatum was rather slow after the grass had reached three or four years of age.

(3) Soil type materially affected the quantity of roots produced by grasses, alfalfa, wheat and corn. Root production was higher in the silty clay loam soil of the south field, than in the fine sandy loam soil of the main field in every case except for alfalfa in the 6 to 12-inch depth.

(4) There was a highly significant difference in root production between species of grass having four and five year old stands. The rank of grasses in root production in descending order are: Native, *B. inermis*, *E. junceus*, *A. smithii*, *A. cristatum*, and *E. canadensis*. Of the species of grass with stands one year old or less, *E. canadensis* produced the greatest quantity of roots.

(5) Only a small quantity of *A. cristatum* roots remained in the soil $1\frac{1}{2}$ and $2\frac{1}{2}$ years after the sod was broken. In some cases there was over one-quarter of a ton of *C. filifolia* roots remaining in the soil 31 years after the sod was broken.

ACKNOWLEDGMENT

The writer is indebted to the former Division of Dry Land Agriculture which is now a part of the Division of Soils, Fertilizers and Irrigation, Bureau of Plant Industry, United States Department of Agriculture, for making the study possible. Indebtedness is also acknowledged to Mr. J. C. Thysell, Associate Agronomist, Northern Great Plains Field Station, Mandan, North Dakota and to Dr. H. E. Myers, major instructor, Department of Agronomy, Kansas State College for their assistance in this study.

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APPENDIX

Grams of alfalfa, corn, grass, sedge, and wheat, and roots in a core of soil 4 15/16 inches in diameter and six inches in depth in the south and main fields, and the SCS quarter. Northern Great Plains Field Station, Mandan, North Dakota, 1944.

Rotation, plot & year seeded	Crop	Weight (grams) 0 to 6 inches depth	Weight (grams) 6 to 12 inches depth	Rotation, plot & year seeded	Crop	Weight (grams) 0 to 6 inches depth	Weight (grams) 6 to 12 inches depth
			SOUTH FIELD				
1G-F (1923)	A. cristatum	2.03	1.22	2G-F (1944)	Wheat	.28	.33
		2.79	1.58			.38	.18
		3.88	1.60			.32	.18
		2.66	1.63			.26	.33
		2.08	1.62			.49	.30
	Sum	13.44	7.65		Sum	1.73	1.32
	Average	2.69	1.53		Average	.35	.26
1G-G (1923)	A. cristatum	4.03	1.61	2G-G (1944)	A. cristatum	.37	.15
		2.31	.87			.40	.12
		4.37	3.20			.46	.17
		3.83	1.77			.36	.15
		6.35	2.88			.36	.12
	Sum	20.89	10.33		Sum	1.95	.71
	Average	4.18	2.07		Average	.39	.14
2G-C (1939)	A. cristatum	3.30	.49	2G-H (1942)	A. cristatum	1.29	.41
		2.33	.85			1.37	.26
		3.56	.58			.76	.15
		2.96	.71			.86	.35
		3.27	.63			1.29	.30
	Sum	15.42	3.26		Sum	5.57	1.47
	Average	3.08	.65		Average	1.11	.29
2G-D (1939)	A. cristatum	3.56	1.40	2G-I (1941)	A. cristatum	2.49	.48
		4.94	2.17			2.59	.40
		3.79	1.36			1.86	.36
		4.12	1.14			3.64	.86
		2.95	2.16			2.25	.42
	Sum	19.36	8.23		Sum	12.83	2.52
	Average	3.87	1.65		Average	2.57	.50
2G-E (1944)	Corn	.28	.20	2G-J (1940)	A. cristatum	3.35	.85
		.16	.27			3.27	.78
		.52	.34			2.64	.56
		.45	.34			3.27	1.11
		.48	.37			3.29	.70

Rotation, plot & year seeded	Crop	Weight (grams) 0 to 6	6 to 12	Rotation, plot & year seeded	Crop	Weight (grams) 0 to 6	6 to 12
		Inches depth				Inches depth	
S[illegible]							
	Sum	1.89	1.52		Sum	15.82	4.00
	Average	.38	.30		Average	3.16	.80
2G-K	A.crista-	3.20	.83	4GD-C	S.virid-	.31	.11
(1940)	tum	3.06	.97	(1943)	ula	.34	.05
		2.17	.65			.28	.09
		2.24	.56			.19	.15
		3.06	.81			.43	.26
	Sum	13.73	3.82		Sum	1.55	.66
	Average	2.75	.76		Average	.31	.13
2G-L	A.crista-	1.31	.62	5GD-A	A.smithii	2.46	.69
(1939)	tum	2.77	.95	(1939)		2.75	.82
		2.07	.51			3.08	.73
		1.73	.47			3.84	.93
		2.39	.59			2.51	1.14
	Sum	10.77	3.14		Sum	14.64	4.31
	Average	2.15	.63		Average	2.93	.86
3GD-A	A.crista-	3.63	.91	5GD-D	A.smithii	.42	.14
(1939)	tum	5.11	1.10			.26	.13
		5.08	1.42			.36	.05
		3.99	1.36			.52	.06
		4.66	1.06			.43	.21
	Sum	22.47	5.85		Sum	1.99	.59
	Average	4.49	1.17		Average	.40	.12
3GD-C	A.crista-	.35	.12	6GD-A	E.canaden-	2.08	.56
(1944)	tum	.44	.15	(1940)	sis	1.49	.34
		.17	.08			.91	.18
		.33	.12			1.34	.43
		.39	.12			1.32	.20
	Sum	1.68	.59		Sum	7.14	1.71
	Average	.34	.12		Average	1.43	.34
4GD-A	A.pauci-	.93	.12	6GD-D	E.canaden-	.71	.17
(1937)	florum	.83	.25	(1943)	sis	.84	.25
		.67	.11			.88	.34
		.94	.29			.35	.32
		1.56	.35			.56	.20
	Sum	4.93	1.12		Sum	3.34	1.28
	Average	.99	.22		Average	.67	.26

Rotation, plot & year seeded	Crop	Weight (grams) Inches depth 0 to 6	6 to 12	Rotation, plot & year seeded	Crop	Weight (grams) Inches depth 0 to 6	6 to 12
		[illegible] FIELD					
7GD-A (1939)	E. junceus	3.81	1.20	10G-H (1940)	A. cristatum	1.14	.65
		5.46	1.66			2.37	.72
		3.56	.72			2.19	.54
		2.81	1.57			2.86	.88
		2.47	.88			3.30	1.03
	Sum	18.11	6.03		Sum	11.86	3.82
	Average	3.62	1.21		Average	2.37	.76
7GD-D (1943)	E. junceus	.56	.31	41GD-B (1939)	B. inermis	4.17	1.67
		.57	.16			3.95	1.26
		.62	.14			5.47	1.40
		.21	.11			4.19	1.74
		.39	.07			4.58	1.52
	Sum	2.35	.79		Sum	22.36	7.59
	Average	.47	.16		Average	4.47	1.52
8GD-A (1939)	A. cristatum	2.62	.95	41GD-E (1944)	B. inermis	.39	.18
		1.91	.55			.44	.24
		3.04	.78			.37	.05
		1.42	.31			.24	.12
		3.21	.97			.34	.24
	Sum	12.20	3.56		Sum	1.78	.83
	Average	2.44	.71		Average	.36	.17
8GD-D (1944)	A. cristatum	.75	.27	42GD-B (1938)	Alfalfa	17.72	4.48
		.40	.15			13.13	3.71
		.44	.13			9.84	1.30
		.35	.13			12.68	3.62
		.57	.19			14.42	4.16
	Sum	2.51	.87		Sum	67.79	18.23
	Average	.50	.17		Average	13.56	3.65
10G-C (1939)	A. cristatum	3.52	.96	42GD-E (1944)	Alfalfa	2.18	.67
		1.98	.83			1.49	.27
		1.90	.45			4.08	.61
		1.31	1.09			2.48	.42
		2.62	.71			2.44	.48
	Sum	11.33	4.04		Sum	12.67	2.45
	Average	2.27	.81		Average	2.53	.49

Rotation, plot & year seeded	Crop	Weight (grams) 0 to 6 inches depth	Weight (grams) 6 to 12 inches depth
		S[illegible] FIELD	
49-A (1944)	Wheat	.35	.14
		.17	.13
		.10	.08
		.24	.09
		.16	.0[illegible]
	Sum	1.02	.52
	Average	.20	.10
49-B (1944)	Corn	.06	.04
		.10	.17
		.04	.04
		.10	.06
		.02	.02
	Sum	.32	.33
	Average	.06	.07
Virgin sod	Native grass	5.31	1.37
		5.82	1.81
		4.33	1.45
		3.34	1.38
		3.63	1.67
	Sum	22.43	7.68
	Average	4.49	1.54
		SCS QUARTER	
Terrace area (1938)	*A. cristatum*	3.49	1.57
		5.29	1.76
	B. gracilis	8.10	2.74
		6.29	2.37
	C. filifolia	7.25	4.07
	Sum	30.42	12.51
	Average	6.08	2.50
		MAIN FIELD	
41GD-B (1938)	*B. inermis*	1.52	.62
		3.14	.71
		3.84	.79
		3.29	.71
		4.09	.77
	Sum	15.88	3.60
	Average	3.18	.72
		MAIN FIELD	
41GD-B	*C. filifolia* (1)	.34	.11
		.28	.08
		.07	.09
		.16	.23
		.20	.15
	Sum	1.05	.66
	Average	.21	.13
41GD-E (1944)	*B. inermis*	.12	.03
		.16	.06
		.11	.05
		.16	.05
		.29	.11
	Sum	.84	.30
	Average	.17	.06
41GD-E	*C. filifolia* (1)	.19	.45
		.29	.22
		.28	.25
		.40	.34
		.44	.23
	Sum	1.60	1.49
	Average	.32	.30
42GD-B (1938-40)	Alfalfa	26.52	8.89
		6.27	1.37
		4.78	2.16
		8.49	.38
		12.48	6.14
	Sum	58.54	18.94
	Average	11.71	3.79
42GD-B	*C. filifolia* (1)	.02	.03
		.10	.04
		.18	.19
		.20	.20
		.16	.14
	Sum	.66	.60
	Average	.13	.12

Rotation, plot & year seeded	Crop	Weight (grams) 0 to 6	6 to 12	Rotation, plot & year seeded	Crop	Weight (grams) 0 to 6	6 to 12
		Inches depth				Inches depth	
		MAIN FIELD					
42GD-E (1944)	Alfalfa	.69	.95	V 49-B (1944)	Wheat	.09	.05
		2.22	1.[illegible]9			.08	.03
		1.93	.77			.03	.03
		.74	.23			.03	.02
		1.09	.34			.07	.03
	Sum	6.67	4.18		Sum	.30	.16
	Average	1.33	.84		Average	.06	.03
42GD-E	C. fili-folia (1)	.32	.33	V 49-B	C. fili-folia (1)	.41	.14
		.33	.06			.60	.77
		.22	.96			.44	.29
		.21	.39			.42	.[illegible]8
		.41	.34			.41	.14
	Sum	1.49	2.08		Sum	2.28	1.42
	Average	.30	.42		Average	.46	.28
V 49-A (1944)	Corn	.06	.04	Virgin sod	Native grass	4.24	1.[illegible]2
		.04	.02			3.17	.97
		.04	.04			1.78	.73
		.07	.03			4.18	.71
		.03	.03			3.79	.95
	Sum	.24	.16		Sum	17.16	4.33
	Average	.05	.03		Average	3.43	.88
V 49-A	C. fili-folia (1)	.43	.24	Virgin sod	C. fili-folia (1)	.21	.19
		.32	.19			1.21	.65
		.46	.25			.07	.65
		.36	.31			.04	.03
		.47	.16			.11	.26
	Sum	2.04	1.15		Sum	1.64	1.78
	Average	.41	.23		Average	.33	.36

(1) *Carex filifolia* roots are those remaining in the soil 31 years after the sod was broken. These roots were hand picked from theother crop roots.

Note: One gram of roots per sample is equivalent to 722 pounds per acre.